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Characterization of Inter-seasonal Climatic Variability through Dry-season Rice productivity in the North-west Region of Bangladesh

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Abstract: Inter-annual climatic variability in Bangladesh is significant and the probability of occurrence of extreme episodic/ climatic events has increased in the last couple of decades and thus threatening food security. Impact of inter-seasonal climatic variability on *Boro* rice (dry season) yield in north-western parts of Bangladesh was analyzed using the historic weather datasets for 1971 to 2010 and MAKESENS model. *Boro* rice yield increased from 1980 onwards and the growth rate picked up with time. Inter-annual and inter-seasonal climatic variability was noticed through maximum and minimum temperatures, rainfall and sunshine hours. In general, temperatures and rainfall showed increasing trends but sunshine hours were decreasing gradually during the study period. Growth rates in average annual maximum, minimum and mean air temperatures were 0.001, 0.016 and 0.009°C year^{-1}, respectively. On regional scale, *Boro* -rice seasonal maximum temperature was decreasing by 0.013°C year^{-1} but minimum and mean temperatures were increasing by 0.024 and 0.006°C year^{-1}, respectively. Annual average sunshine hours in the study location were in decreasing trend by 0.027 hr year^{-1}, but reduction in seasonal sunshine hours was 0.035 hr year^{-1}. Inter-seasonal climatic variability was characterized through the *Boro* -rice yields in four test regions of north-west region of Bangladesh. Trend line equations were evolved for assessing the impact of climatic variations on *Boro* rice yield. If maximum temperature changes by 1o C, *Boro* rice yield could be increased by 0.13 t ha^{-1}, but it would reduce by 0.34 t ha^{-1} with one degree rise in minimum temperature. If sunshine hour decreases by 1 hr, *Boro* rice yield would decrease by 0.70 t ha^{-1} in study locations. Combined effects of maximum and minimum temperatures and sunshine hours showed significant influence on grain yields of *Boro* rice. These imply that temperature tolerant and solar radiation use-efficient rice varieties need to be bred for combating climate change impact in Bangladesh. There is a need to identify optimum sowing/transplanting window for the region, choice of suitable cultivars/ideo-types, and adoption of appropriate water and nutrients management strategies and adoption of

appropriate resource conservation technologies for sustainable *Boro* rice production in Bangladesh.

Keywords: *Boro* rice, MAKESENS model, temperature, rainfall, sunshine hour, grain yield.

Introduction

Despite high population pressure on land and other natural resources, Bangladesh has achieved near self-sufficiency in food grain production. This has mostly happened because of replacement of local varieties by the modern high yielding varieties (Bayes et al., 1985; Baffes and Gautam, 2001). Most countries including Bangladesh consider domestic food grain production as an important factor for food price stabilization and food security and thereby pursue food self-sufficiency policies to avoid macroeconomic and political instability from food price shocks (Byerlee et al., 2005; Deb et al., 2009). However, the success of food self sufficiency has been challenged by the population growth rate of nearly 1.38% per annum (Alam, 2014) and by climate change vulnerability.

Most of the researchers hypothesize that the demand for cereal foods, especially for rice, is expected to rise by over 1.5% per annum for the next few decades. An estimate indicates that 37 million tons of food grains will be required for 172 million people by the year 2020 (Alam, 2014). However, net cultivated area will reduce to about 7.89 million hectares by 2025 to feed about 184 million people (Bhuiyan et al., 2007). Moreover, floods, salinity and droughts threaten food security of rural people (Bala and Hossain, 2010; World Bank, 2010). In coming years, these hazards are likely to aggravate due to climate change (FAO, 2006; Yu et al., 2010; Ahsan et al., 2011; IPCC, 2013; Vidal, 2013, Singh and Kalra, 2016). There are variable reports on rainfall amounts and distribution (Ahmed et al., 1992; Rahman et al., 1997), but increase in temperature is likely to be 0.5-1.1°C per century (Ahmad et al., 1996; Mondal and Wasimi, 2004). Besides, increasing trend of mean maximum and minimum temperatures in some seasons and decreasing trend in some others during 1961-1990 were also observed (SMRC, 2003; Rahman and Alam, 2003; Islam and Neelim, 2010).

The concern of climate change is the potentially disastrous consequences on crop agriculture and thus food security in many parts of the world, particularly in developing countries (FAO, 2007; IPCC, 2007a; Mertz et al., 2009; WB, 2010; Roudier et al., 2011). Bangladesh is considered as one of the most vulnerable countries to climate change because of its location, dominance of floodplains, sea level, high population density and low economic and technological capacity (MoEF, 2005; DoE, 2007; Shahid and Behrawan, 2008; Pouliotte et al., 2009; Huq and Rabbani, 2011).

Crop agriculture in Bangladesh is mainly dominated by rice, occupying almost 80% of the total cropped area and accounts for more than 90% of total grain production (Alauddin and Tisdell, 1987, 1991; BBS, 2009;

Asaduzzaman et al., 2010). So, it clearly dictates the necessity of assessing the effects of climate change on rice production in Bangladesh to ensure food security and economic growth in future. However, empirical investigations of the influence of climate change on crop agriculture in this country are limited (Mahmood, 1998; Paul, 1998; Ali, 1999; Rahman, 2000; Rashid and Islam, 2007).

North-west part of Bangladesh is a food granary. Impacts of climatic variability and extreme events can impair food security of that locality as predicted that cereal production in Bangladesh could be decreased by 10-25% due to increase in temperature (Peng et al., 2004; CCC, 2009). However, spatial distribution of trends is not available. Climatic variability and extreme climatic events are concerns, and there is a need to evaluate climatic variability through growth and yield of important crops. There is a need to know the appropriate management options to face the challenges of extreme episodic and episodic events. The knowledge gained would be effectively useful in understanding the agri-response with the future climate change scenarios. Crop simulation tools are effective in this exercise (Aggarwal et al., 2006; Kalra et al., 2007), but the regression based approaches by understanding the dependence of growth and yield of crops with the historic weather datasets are also important. Moreover, such climatic variability are not reported with respect to crop yield variations in particular for this region. Regression models that use historical data on both climate variables and yields are more capable of providing accurate estimates of the changes in crop yield as a result of changes in climate variables (Isik and Devadoss, 2006; Lobell and Field, 2007; Almaraz et al., 2008; Joshi et al., 2011). Therefore, the present study was conducted to analyze the trend of climatic variability and climate change and its impact on *Boro* rice production in north-west regions of Bangladesh.

Methodology

Site description

The study area i.e. north-west part of Bangladesh lies in 23°47´45″ N to 25° 46´34″ N latitude and 88°00´37″ E to 89°49´11″ E longitude, and covers approximately 23,295 km^2. Total population of the area is 22.93 million of which more than 80% people live in rural areas and directly or indirectly depend on agriculture. The density of population is approximately 860 persons per square kilometer. The study area belongs to dry humid zone with annual average rainfall between 1,400 and 1,900 mm. Seasonal distribution of rainfall shows that almost 92.7% rainfall occurs during May to October. Less than 6% rainfall occurs during *Boro* rice crop growing period (January to April). Rainfall also varies year to year basis. Inter-annual variability of non-monsoonal rainfall in the area is more than 50% (Shahid, 2008). Temperature in the region ranges from 25°C to 40°C in the hottest season and 8°C to 25°C in the coolest one.

The economic activities of the region are agriculture based. About 74.8% land of the study area is used for agriculture, of which about 86% is used for dry season crop cultivation. High yield variety (HYV) of *Boro* rice is the dominant crop, which shares almost 81.2% of total cultivated crop in dry season. About 6.5 million metric ton of *Boro* rice is produced in the study area, which shares 15.2% of total food production in Bangladesh (BBS, 2013).

Groundwater is the main source of irrigation for *Boro* rice fi eld. Recent declination of groundwater level during dry season in north-west Bangladesh has posed a major threat in irrigated agriculture system (Samsudduha et al., 2009; Rahman and Mahbub, 2012) along with frequent droughts (Shahid, 2008; Shahid and Behrawan, 2008). In last 40 years, the area suffered eight droughts of major magnitude (Paul, 1998). Recurrent droughts and availability of irrigation equipments have made the people dependent on groundwater as a source of irrigation covering about 79% area in Bangladesh (BADC, 2012). Ever increasing groundwater extraction for irrigation and no increase in rainfall have caused the groundwater level falls to the extent of not getting fully recharged (GoB, 2012).

Data source and temporal trend analysis

Inter-and intra-climatic variability was characterized through long-term climatic elements trend-analyses and through growth and yield response of *Boro* -rice for north-west part of Bangladesh. Temperature, rainfall and sunshine duration data were obtained from four stations of Bangladesh Meteorological Department (BMD) situated in the study site and rice grain yield data from Bangladesh Bureau of Agricultural Statistics. The Mann–Kendall trend test (Mann 1995) was used to detect trends in the time series data and the test statistic distribution was explained by Kendall (1975) for testing nonlinear trends and turning points. The test assumes a monotonic trend and thus rejects the presence of any seasonal or other cycles in the data. The Mann-Kendall test is preferred when various stations are tested in a single study (Hirsch et al., 1991). In the present study, confidence levels of 99%, 95% and 90% signify the positive or negative trends determined by the test statistic. More details of the Mann-Kendall test and its statistical ability are documented in Yue et al. (2002). Another nonparametric test known as Sen's slope estimator (Su et al., 2006) was used to determine the magnitude of change in the climatic parameters while the Mann-Kendall test reveals the direction of change or trend. The present study computes the confidence interval at two different confidence levels: $p = 0.01$ and $p = 0.05$, resulting in two different confidence intervals, Mann-Kendall test for trend and Sen's slope estimates MAKESENS was used for detecting and estimating trend (Salmi et al., 2002).

Trend analyses, for inter-annual and inter-seasonal, maximum, minimum and mean temperatures, rainfall and sunshine duration were carried out using historic datasets of the four test locations in 1971-2010.

The descriptive statistics for productivity of *Boro* rice and seasonal climatic elements was prepared. Growth rates of area and productivity of *Boro* rice in the four test regions was also worked out.

Annual and seasonal deviations from the trend line, in temperature, rainfall and sunshine hours and *Boro* productivity, were computed. The following equation was used for this purpose:

$$\text{Percent deviation } (\%) = \{(Yi - \bar{Y})/\bar{Y}\} * 100 \qquad (1)$$

where, Yi = mean values of each climatic parameter or yield

i = number of years i.e. 1, 2, 3, n

Y = normalized (or trend) value of each climatic parameters or yield

Trend line in the climatic element over years shows the gradual climate change trend, and the percent deviation of each year from the trend line is basically the inter-annual as well inter-seasonal climatic variability.

Vulnerability of an agricultural crop depends on timing, duration and magnitude of a hazard, type and growth stage of a crop, physical settings of an area, and different types of capacities available to respond. In this study, quantitative assessment of vulnerability of *Boro* rice was made by comparing the deviation of crop yields with main climatic elements viz. temperature and sunshine hours, rainfall is not taken in present study as the *Boro* rice in this region is grown under non-limiting supply of water.

The combined effect of absolute maximum and minimum temperatures and sunshine hours on *Boro* rice yield was computed through multiple regression analyses. The predicted yield of *Boro* rice based on climatic parameters was computed as:

$$Y\mathit{Boro}_t = \alpha_1 Tmax_t + \alpha_2 Tmin_t + {}_3SSH_t + C_t \qquad (2)$$

where, $YBoro_t$ = Yield of *Boro* rice in t ha^{-1}

$Tmax_t$ = Average maximum temperature (°C) from November to May

$Tmin_t$ = Average minimum temperature (°C) from November to May

SSH_t = Average sunshine hours (hrs) from November to May

C_t = Error term

t = Time (i.e. year)

α_1, α_2 and α_3 = Regression coefficients

The number days for occurrences of extreme temperatures (Tmin 35°C) and rainfall (daily rainfall > 50mm) was computed from the daily data of the study locations during 1971-2010 and find out its effects on *Boro* rice production. The extreme minimum temperature was considered below 10°C, because physiological activities are suspended below this temperature based on the DSSAT and INFOCROP model. The maximum temperature beyond 35°C was considered extreme because spikelet sterility takes place (Peng, et al., 2004). *Boro* rice is grown by fully irrigated situation in dry season in Bangladesh and farmers generally irrigated 50-70 mm of irrigation water by levee management. Therefore, rainfall greater than 50 mm was considered as extreme one.

RESULTS AND DISCUSSION

Inter & Intra-Seasonal climatic Variability and *Boro*-rice Productivity

Tab. 1 shows descriptive statistics, in terms of basic statistical parameters with absolute values, for *Boro* rice productivity and seasonal climatic elements aggregated over years, for four test locations. The Table clearly shows the extent of variations through basic dispersion elements. The basic intention is to capture the climatic variability through yield of *Boro* rice.

Boro rice area and productivity trends

Boro rice area and productivity increased continuously from 1981 to 2010 (Tab. 2) due to adoption of improved technologies such as modern high yielding varieties, fertilizers, cultural managements and especially the ensured irrigation facilities that increased. Although the contribution of *Boro* rice is more in total rice production of Bangladesh, change in temperature, rainfall and sunshine duration could play a negative role in its production (IPCC, 2013).

Statistics	Variables															
	Yield (t ha^{-1})				Maximum temperature (°C)				Minimum temperature (°C)				Sunshine hours			
	Rajshahi	Bogra	Rangpur	Dinajpur	Rajshahi	Bogra	Rangpur	Dinajpur	Rajshahi	Bogra	Rangpur	Dinajpur	Rajshahi	Bogra	Rangpur	Dinajpur
Mean	4.25	4.26	4.08	4.16	30.14	29.65	28.32	28.82	17.08	17.58	16.33	16.33	7.82	7.82	7.36	7.12
Std. deviation	0.95	0.86	0.90	0.78	0.51	0.57	0.79	0.56	0.58	0.48	0.90	0.55	0.39	0.96	0.66	0.40
Maximum	6.40	6.16	6.06	6.15	31.26	31.17	30.83	29.83	18.10	18.60	17.56	17.33	8.71	9.59	8.51	8.21
Minimum	2.77	2.42	2.29	2.54	29.00	28.56	26.14	27.37	15.50	16.57	13.37	14.87	7.04	5.84	5.81	6.54
Skewness	0.42	0.08	0.42	0.80	-0.10	0.10	0.53	-0.07	-0.66	-0.18	-1.36	-0.34	-0.08	-0.03	-0.40	0.72
Kurtosis	-0.43	0.63	0.18	0.85	-0.28	0.03	2.36	-0.17	0.31	-0.53	2.49	-0.14	-0.19	-0.44	0.44	0.79

Tab. 1 - Descriptive statistics of the historic *Boro* rice yield and weather datasets (1971-2010) used for north-west region of Bangladesh.
Tab. 1 - Statistiche descrittive delle produzioni storiche di riso Boro *e dataset climatici (1971-2010) usate nel nord-ovest del Bangladesh.*

Year	Rajshahi region				Dinajpur region				Rangpur region				Bogra region			
	Area (ha)	GR yr^{-1}	Prod. (t ha^{-1})°	GR yr^{-1}	Area (ha)	GR yr^{-1}	Prod. (t ha^{-1})	GR yr^{-1}	Area (ha)	GR yr^{-1}	Prod. (t ha^{-1})	GR yr^{-1}	Area (ha)	GR yr^{-1}	Prod. (t ha^{-1})	GR yr^{-1}
1970-71	38461	-	3.06	-	5425	-	2.54	-	14170	-	3.14	-	14818	-	3.43	-
1979-80	38706	25	3.26	0.02	7053	163	3.93	0.14	32109	1794	3.69	0.06	23257	844	4.26	0.08
1989-90	172830	13412	3.64	0.04	63040	5599	3.95	0.00	174449	14234	3.97	0.03	170251	14699	3.87	-0.04
1999-00	294988	12216	4.86	0.12	199891	13685	4.11	0.02	324320	14987	4.70	0.07	236219	6597	4.50	0.06
2009-10	372370	7738	6.03	0.12	286916	8703	5.86	0.18	464190	13987	6.06	0.14	258367	2215	6.03	0.15

Tab. 2 - Decadal changes in *Boro* rice area and productivity in north-west region of Bangladesh.
° Paddy (Adopted from BBS, 1973, 1982, 1991, 2001 and 2011), GR= Growth rate
Tab. 2 - Variazioni decennali nell'area di produzione e nella resa di riso Boro nel nord-ovest del Bangladesh.
° Risaia (Adottata per BBS, 1973, 1982, 1991, 2001 e 2011), GR= tasso di crescita.

Annual and seasonal temperature patterns

Analysis of long term climatic data shows a fair degree of inter- and intra seasonal variations in temperature changes. The Mann-Kendall trend test showed a significant increase in minimum and mean temperatures. The magnitude of change assessed by Sen's slope showed that average annual maximum, minimum and mean temperatures have increased by 0.001°C year^{-1}, 0.016°C year^{-1} ($p < 0.001$), and 0.009°C year^{-1} ($p < 0.05$) respectively during 1971-2010 (Fig. 1). However, *Boro* seasonal maximum temperature decreased by 0.013°C year^{-1} and seasonal minimum and mean temperature increased by 0.024°C year^{-1} ($p < 0.001$) and 0.006°C year^{-1}, respectively. Decreasing trend of maximum temperature in *Boro* season might be because of high irrigated areas in that location. Shahid (2010) also reported increased annual mean and minimum temperatures by 0.005°C year^{-1} and 0.013°C year^{-1}, respectively in the same region during 1958-2007. Hasan and Rahman (2013) showed that maximum temperature was increasing by 0.005°C year^{-1}, with maximum increase in November (0.02°C year^{-1}). The minimum temperature was also increasing by 0.014°C year^{-1}, but the maximum value (0.027°C year^{-1}) was observed in February. Ayub and Miah (2011) also reported that maximum temperature in Rajshahi and Bogra area was increasing by 0.01 and 0.017°C year^{-1}. Studies conducted at SAARC Meteorological Research Centre revealed that mean temperature in pre-monsoon season decreased. But in other seasons of the year temperature generally increased. Increase in temperature would greatly affect the productivity of temperature sensitive crops, especially rabi crops. Besides, temperature increase would shorten winter season, which would adversely affect the vegetative as well as reproductive growth of most of the winter crops and consequently reduce yield.

Based on 40-years (1971-2010) data and projection through MAKESENS model, which produce the monotonic trend of the climatic parameters based on the historical data without changing over time and it is found that annual mean temperature will be increased by 0.53°C, 0.71°C and 1.17°C, respectively during 2030, 2050 and 2100 A.D. However, *Boro* growing season temperature would increase by 0.31°C, 0.41°C and 0.67°C, respectively during same projected years (Tab. 3). The Table also shows the standard deviation value within parenthesis. Agarwala et al. (2003) reported that annual temperature will be increasing by 1.0°C, 1.4°C and 2.4°C, respectively; whereas the winter temperature will be increasing by 1.1°C, 1.6°C and 2.7°C, respectively during 2030, 2050 and 2100 in Bangladesh. Our finding is closer, but a little bit lower than their findings. Based on data from 1961 to 1990, Karmakar and Shrestha (2000) reported that the projected annual maximum temperature in Bangladesh will increase by 0.4 and 0.73°C in 2050 and 2100, respectively, which is closer to our findings.

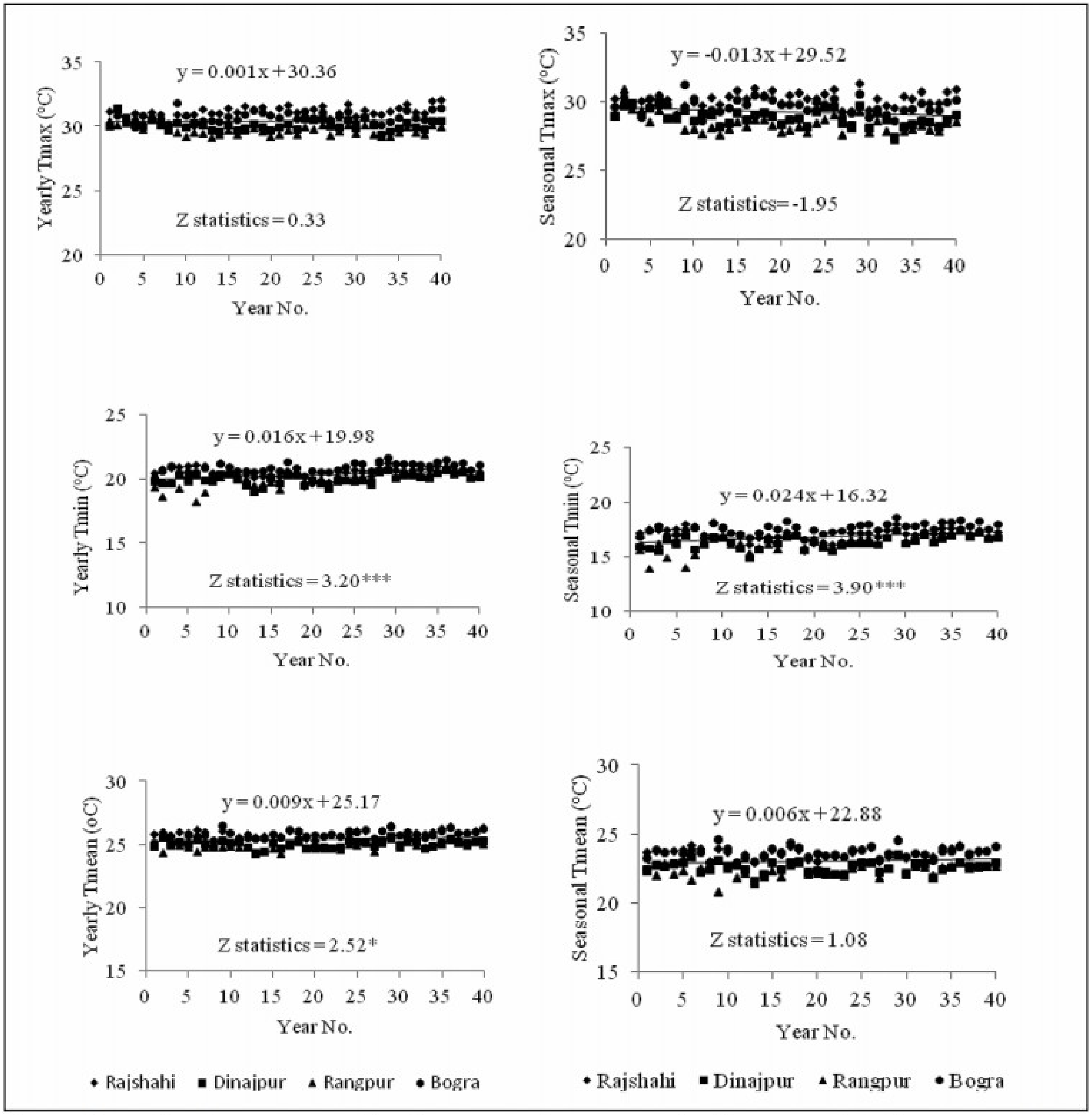

Fig. 1 - Observed trends in average yearly and *Boro* seasonal temperature: (a & b)-maximum, (c & d)- minimum and (e & f)- mean in north-west region of Bangladesh, year no. starts from 1971 (* p< 0.05; ** p<0.01; *** p<0.001).
Fig. 1 - Andamenti osservati nelle medie annuali e nelle temperature nella stagione del riso Boro *(a & b)- massime, (c & d)- minime e (e & f)- medie nel nord-ovest del Bangladesh, a partire dal 1971 (* p< 0.05; ** p<0.01; *** p<0.001).*

Shahid, 2011 projected that mean temperature is likely to increase by 0.8°C in 2025, 1.4°C in 2050, 1.9°C in 2075 and 2.4°C in 2100. In *Boro* season of 2100, the maximum increase of mean temperature would be about 3.0°C during January and minimum increase by 1.4°C in July, which is closer to our findings. However, present investigation reveals that increase in temperature in north-west region of Bangladesh would be much more less than projected values by others (Karmakar and Shrestha, 2000; Agarwala et al., 2003; Shahid, 2011; IPCC, 2013). Most of these reports are based on GCMs outputs, which usually require accurate regional calibration and also the results, vary from model to model.

Year	Mean temperature change (°C)		Average rainfall change (%)	
	Annual	*Boro* season	Annual	*Boro* season
2030	0.53 (1.2)	0.31 (1.8)	10.6 (2.1)	5.6 (6.6)
2050	0.71 (1.4)	0.41 (2.1)	14.3 (2.5)	7.5 (8.2)
2100	1.17 (1.8)	0.67 (2.4)	23.3 (3.8)	12.2 (10.6)

Tab. 3 - MAKESENS projections for changes in annual and Boro seasonal temperature and rainfall in north-west region of Bangladesh.
Figures in the parentheses indicate standard deviation.
Tab. 3 - Proiezioni MAKESENS per le variazioni annuali e stagionali delle temperature e delle precipitazioni nel nord-ovest del Bangladesh.
Le figure in parentesi indicano la deviazione standard.

In general, mean annual temperature in northwest region prevails at around 25.17° C and average minimum and maximum temperatures at 19.98° C and 30.36° C, respectively. Similarly, mean annual, minimum and maximum temperature during *Boro* season prevails at 22.88° C, 16.32° C and 29.52° C, respectively. High temperature is generally observed in April and May and the lowest in January (MoEF, 2008).

Mean annual temperature in Rajshahi region is around 25.75° C and mean minimum and maximum temperatures are 20.83° C and 30.87° C, respectively. High temperature (as high as 45.1°C) is generally observed in April and May and the lowest (3.4°C) in January (CEGIS, 2013).

Climate change scenarios by 2050 as analyzed by IPCC (2013) indicated that temperature is likely to increase by at least 1.8°C under reduced green house gas emission conditions and 3.4°C in worst situations. Maximum temperature will be more than 35°C during March to May, the flowering period of *Boro* rice making it susceptible to sterility (BRRI, 2011) indicating that heat tolerant varieties need to be bred and disseminated among the farmers to continue rice production.

Decrease in rice yield due to increased temperature is primarily due to reduced duration of the crop (Shahid, 2011; Karim et al. 1999; Rani and Maragatham, 2013). The other reasons for reduction in yield could be due to higher respiration rates and increased evaporative demand. There would be corresponding declines in potential water productivity, with and without CO_2 fertilization seems to be diminishing (Long et al., 2005).

Annual and seasonal rainfall patterns

The mean annual rainfall in the country is about 2666 mm, but there exists a wide spatial and temporal variation in distribution. Annual rainfall ranges from 1200 mm in the west to over 5000 mm in the east and north-east. The average annual rainfall of the study region increased by 1.38 mm year^{-1}, but *Boro* season rainfall showed increased in trend by about 0.44 mm year^{-1} (Fig. 2). The average *Boro* season rainfall in north-western region of Bangladesh varies from 69 mm to 796 mm, with an average of about 333 mm, which is very less compared to irrigation water requirement. Mean annual total rainfall varied from 1377 to 1487 mm in Rajshahi region. Dry season rainfall was only 16-18% of the mean annual precipitation (CEGIS, 2013). Groundwater table in Bangladesh is declining at an alarming rate making shallow tube wells non-operating in many parts of the country during dry period. Ecosystem and human activities suffer considerably because of reduced availability of water in the dry season because of seasonal high variability of water availability. It is anticipated that the current sufferings due to lower water availability in the dry season will be accentuated not only by climate change, but also by increase in demand exerted by increased population.

Hussain (2011) reported increased rainfall during March through November in both 2050 and 2070 A.D., based on Geophysical Fluid Dynamics Laboratory Transient (GFDL-TR) Global circulation model; but decreased rainfall pattern was reported in the same period based on Hadley Center (HadCM2) Global circulation model. Shah et al. (2013) also reported changing precipitation pattern, with mean annual precipitation and dry season rainfall decreasing in Bangladesh. Rahman et al. (2012) reported increased rainfall by 107% in dry season (December-February) by using Regional Climate Model (RegCM3, version 3), but increased or decreased rainfall situations may prevail in dry season (Hussain, 2011).

If winter rainfall increases during 2050 and 2070 (Rahman et al., 2012), non-rice crops establishment at the right time would be hampered. Although it will reduce irrigation cost of *Boro* rice, increase in temperature and rainfal l would decrease rice productivity (Saseendran et al., 2000).

Annual total rainfall is likely to increase and thus might create flooding situation in wet season. On the other hand, minor increase in *Boro* seasonal rainfall will not significantly influence the irrigation amount and cost (Tab. 3).

Annual and seasonal sunshine hours

Annual average sunshine hours in our study locations were in decreasing trend (Mann-Kendall test, $Z = -6.05$, $p< 0.001$). Sen’s slope estimator shows that annual sunshine hours were decreasing by 0.027 hrs year^{-1} from 1971 to 2010. However, *Boro* seasonal sunshine hours decreased by 0.035 hrs year^{-1} ($p < 0.001$) for the same period (Fig. 3). These indicate that there would be reduction in *Boro* rice yield because of reduced sunshine hours, if radiation-efficient varieties are not developed and cultivated by the farmers.

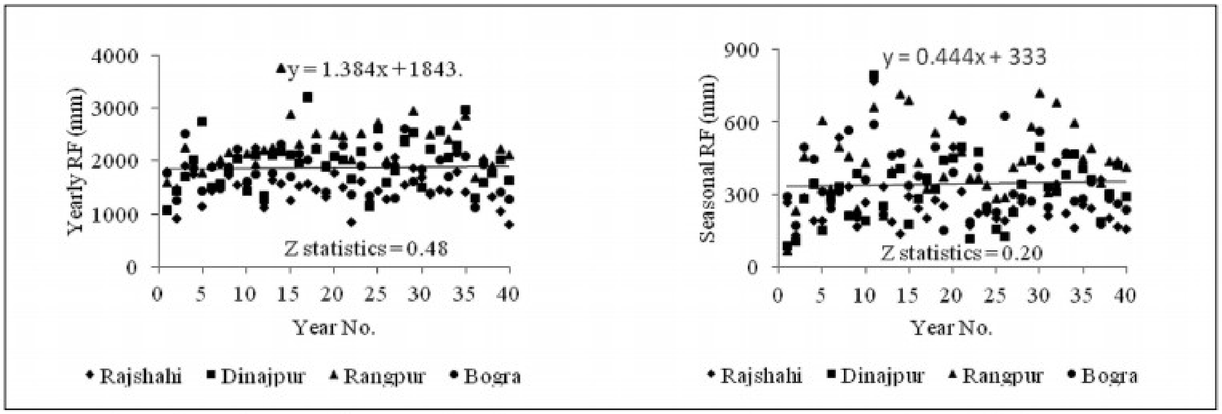

Fig. 2 - Observed trends in rainfall: (a)- yearly and (b)- Boro season in north-west region of Bangladesh.
Fig. 2 - Andamenti osservati nelle precipitazioni: (a)- annuali e (b)- nella stagione del riso Boro nel nord-ovest del Bangladesh.

Shah et al. (2013) also reported that annual sunshine hour will be reduced by about 5.3% per decade, whereas it was only 2.03 to 9.48% per decade with an average of 4.61% per decade in *Boro* season indicating that rice yield reduction is likely in future due to climate change. Similar findings were reported by Vijayalakshmi et al. (1991). The importance of sufficient sunlight on paddy plant can easily be recognized as the number of tillers and panicle production increases with higher light intensity and quantity (Grist, 1983; Shi et al., 2002).

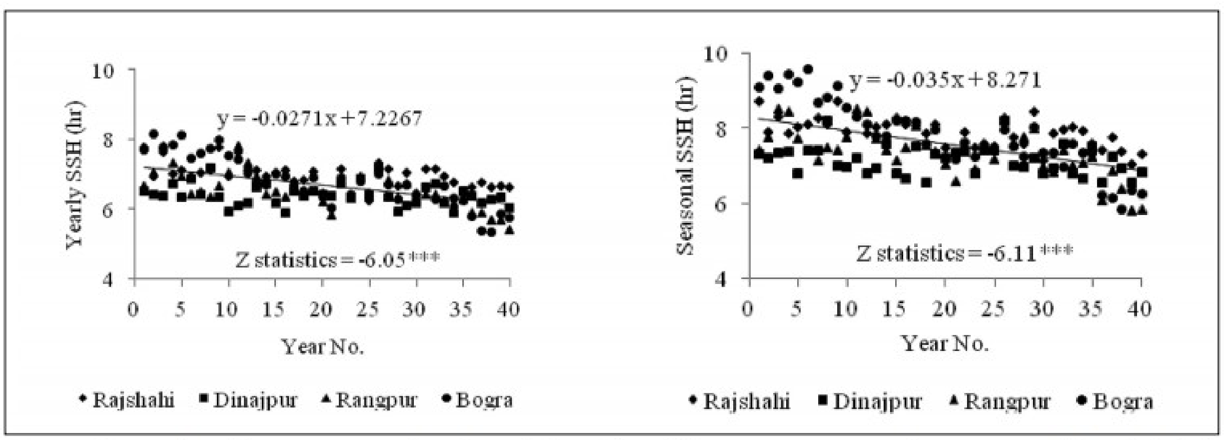

Fig. 3 - Observed trends in average sunshine hours: (a)- yearly and (b)- Boro season in north-west region of Bangladesh (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).
Fig. 3 - Andamenti osservati nella media delle ore di sole: (a)- annuale e (b)- nella stagione del riso Boro nel nord-ovest del Bangladesh (p< 0.05; ** p<0.01; *** p<0.001).*

Inter-seasonal climatic variability effects on *Boro* rice yield

Average maximum temperature of study regions varied from 28.3 to 30.1°C and average rice yield varied from 4.08 to 4.26 t ha^{-1}. Grain yield was directly related with the increase in maximum temperature during *Boro* season upto maximum threshold level of 35°C (Hussain, 2008). If maximum temperature increases by 1°C, *Boro* rice yield is likely to increase by 3.19% i.e. about 0.13 t ha^{-1}. Since north-western part is cooler during dry season, slightly increased temperature in early growth stages of rice will provide favorable environment for growth and development of rice plants.

On the contrary, average minimum temperature in the study regions varied from 16.3 to 17.6°C. *Boro* seasonal minimum temperature was in increasing trend (Fig. 1). If minimum temperature increases by about 1° C, *Boro* rice yield would be reduced by 8.04%, i.e. about 0.34 t ha^{-1} (Fig. 4).

The cultivation of *Boro* rice is generally started from November-December i.e. winter months and ended on April-May i.e. the summer months. Over the locations, the extreme minimum temperature prevails during December to February, especially in January (Table 4). So, farmers used to delay *Boro* rice transplant in study areas to avoid cold injury compared to other regions of Bangladesh. On the other hand, the extreme maximum temperature prevails during March to May, with maximum prevalence in April (Tab. 4). Late planted *Boro* rice flowers in April and thus spikelet sterility is a must if temperature exceeds 35°C. Extreme rainfall in dry season is a rare phenomenon in Bangladesh, although *Boro* rice sometimes suffers from flash flood damage during ripening stage.

Mean temperature during *Boro* season showed increasing trend (Fig. 1). If mean temperature increases by about 1°C, *Boro* rice yield reduction would be 2.54% i.e. about 0.11 t ha^{-1} (Fig. 4), which is very much similar to the findings of Mahmood et al., 2012 and Mabe et al., 2014. Ho et al. (2013) reported 16-20% yield reduction due to 2°C temperature rise in Vietnam. Peng et al. (2004) reported that grain yield declined by 10% for each 1°C increase in minimum temperature in dry season, whereas the effect of maximum temperature on crop yield was insignificant. Under elevated temperature of 2°C and 4°C, the grain yield was 13.3 and 23 percent less from the ambient temperature (Rani and Maragatham, 2013). Sarker et al. (2012) showed that maximum and minimum temperature had statistically significant adverse and positive effect, respectively on *Boro* rice yield. The country is predicted to experience an increase in average temperature of 1.4°C by 2050 and consequently, the rice production is likely to decline by 8-17% (IPCC, 2007b).

Boro rice area and productivity on the increase, puts more pressure on groundwater resources for *Boro* rice production in north-west region of Bangladesh (Aziz et al., 2015), which is a matter of concern. Along with the climate change / climatic variability, we need to address other biotic and abiotic stresses playing role under the increased scenario of intensive agriculture.

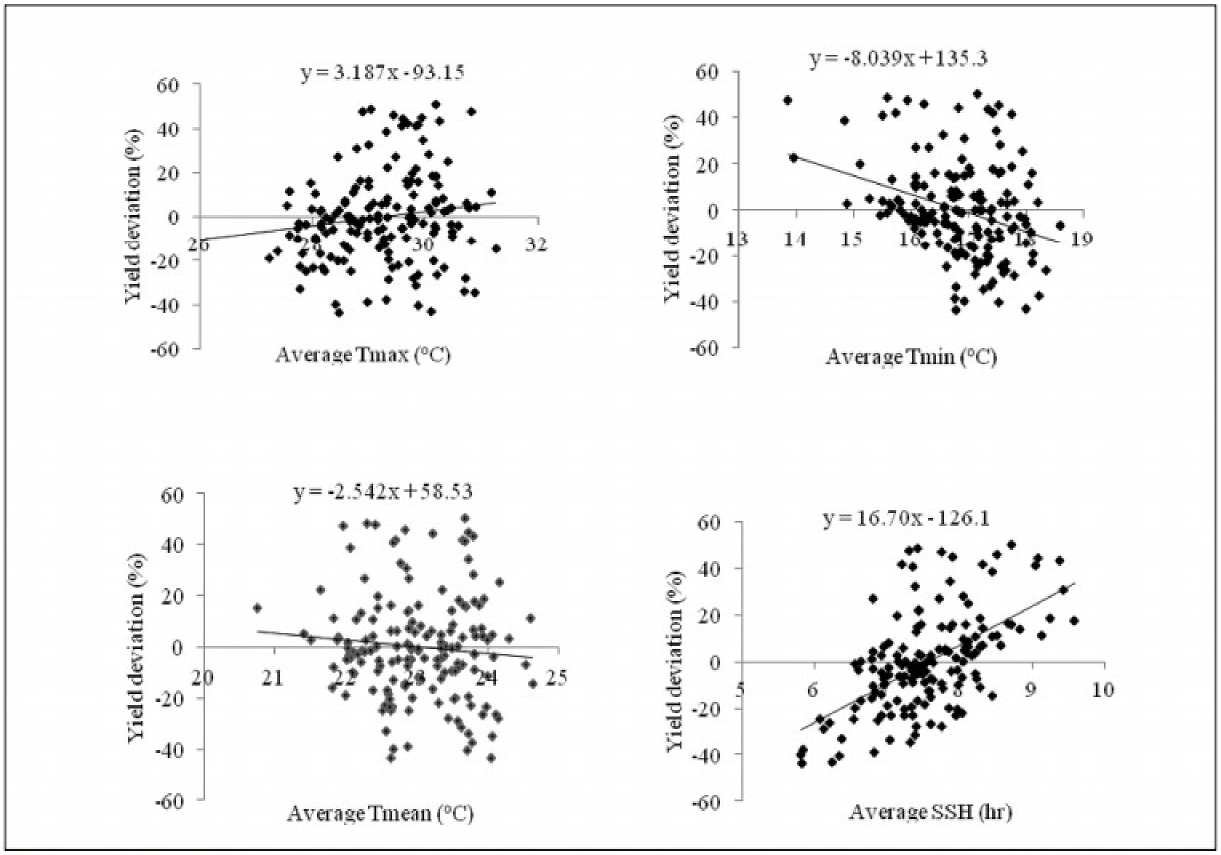

Fig. 4 - Relationship of percent deviation in boro rice yield with growing season weather parameter: (a) maximum temperature, (b) minimum temperature, (c) mean temperature and (d) avrerage sunshine hours in the north-west region of Bangladesh.

Fig. 4 - Relazione tra la deviazione percentuale nella produzione di riso Boro e i parametri climatici registrati nella stagione di crescita: (a) temperatura massima, (b) temperatura minima, (c) temperatura media e (d) media delle ore di sole nel nord-ovest del Bangladesh.

According to IPCC estimates, increasing temperature and changing rainfall pattern along with flooding, drought and salinity, Bangladesh might face a decline in crop production by 2050. Against 1990 base year, the predicted declines were 8% in rice and 32% in wheat (MoEF, 2009). Hussain (2008) predicted 1.2-9.5% increase in *Boro* rice production by 2050 using different models, assuming the threshold temperature not exceeding 35°C.

Average sunshine hours in the study regions varied from 7.12 to 7.82 and both annual and seasonal showed declining trend (Figure 3). If sunshine hour decreases by 1 hour, *Boro* rice yield is likely to decrease by 16.7% i.e. about 0.7 t ha^{-1} (Figure 4). Shah et al. (2013) reported reduced annual sunshine hour by about 5.3% per decade, whereas it was only 2.03 to 9.48% per decade with an average of 4.61% per decade in *Boro* season indicating reduction in rice yield. Vijayalakshmi et al. (1991) also reported reduced grain yield and yield components with the reduction of solar radiation.

The interaction of average maximum and minimum temperatures and sunshine hours on rice yield was computed through multiple regression analyses. The predicted yield was in close agreement with the observed yield (Fig. 5). Our analyses indicate that increased in average minimum temperature and reduction in sunshine hours will play a dominant role ($p < 0.01$) in reduction of *Boro* rice yield in future. The model has an F-value of 27.32 with a p-value of 0.001 This implies that the overall model result was statistically significant at 1% level of probability. The R^2 value indicates that 35% of the variations in *Boro* rice yields are explained by the climatic variables. The t-value of the average minimum temperature was 5.07 and for average sunshine hours was -7.34, which were statistically significant at 1% level of probability.

Year	Rajshahi			Bogra			Rangpur			Dinajpur		
Tmin<10°C												
	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb
1971-80	0-5 (0.5)	0-13 (4.7)	0-7 (2.9)	0-6 (1.7)	0-12 (4.9)	0-8 (2.8)	0-21 (2.8)	3-24 (8.8)	0-17 (2.8)	0-9 (0.9)	3-11 (6.0)	0-11 (2.1)
1981-90	0-10 (4.2)	5-22 (11.6)	1-8 (4.3)	0-3 (0.6)	0-19 (4.8)	0-5 (0.9)	0-4 (1.3)	3-20 (10.6)	0-12 (3.7)	0-8 ((2.6)	2-23 (12.1)	0-12 (3.3)
1991-00	0-17 (5.4)	8-22 (15.2)	0-7 (2.8)	0-1 (0.3)	1-15 (7.6)	0-2 (0.3)	0-6 (1.4)	5-20 (11.3)	0-6 (2.1)	0-11 (3.3)	3-22 (13.9)	0-8 (2.7)
2001-10	0-9 (3.2)	4-23 (13.3)	0-13 (4.4)	0-6 (1.1)	1-17 (5.7)	0-7 (1.3)	0-6 (1.4)	0-20 (7.6)	0-5 (2.2)	0-5 (2.5)	1-21 (10.7)	0-8 (2.7)
Tmax>35°C												
	Mar	Apr	May	Mar	Apr	May	Mar	Apr	May	Mar	Apr	May
1971-80	0-14 (7.7)	12-25 (18.4)	0-12 (5.7)	0-13 (6.8)	1-25 (15.6)	0-28 (6.0)	0-5 (0.6)	0-10 (2.3)	0-29 (3.2)	0-8 (1.5)	0-12 (4.8)	0-15 (4.9)
1981-90	2-20 (10.8)	13-30 (20.3)	4-22 (13.8)	0-9 (3.4)	2-23 (12.5)	0-18 (6.9)	0-3 (0.9)	0-11 (6.4)	0-7 (2.7)	0-7 (2.3)	2-20 (11.2)	0-22 (5.3)
1991-00	0-19 (9.4)	6-28 (19.4)	8-24 (16.6)	0-4 (1.2)	1-22 (10.7)	2-18 (9.0)	0-3 (0.6)	0-30 (10.9)	0-8 (3.3)	0-6 (2.1)	1-21 (10.7)	0-21 (7.9)
2001-10	1-19 (8.5)	8-26 (19.2)	8-25 (16.2)	0-4 (1.3)	1-12 (6.4)	2-18 (9.4)	0-1 (0.2)	0-6 (1.6)	1-10 (2.9)	0-7 (1.8)	0-16 (5.1)	2-10 (4.7)
Rainfall>50mm												
	Mar	Apr	May	Mar	Apr	May	Mar	Apr	May	Mar	Apr	May
1971-80	0-0 (0.0)	0-1 (0.1)	0-1 (0.2)	0-0 (0.0)	0-1 (0.1)	0-3 (0.7)	0-0 (0.0)	0-2 (0.8)	0-0 (0.0)	0-0 (0.0)	0-0 (0.0)	0-0 (0.0)
1981-90	0-0 (0.0)	0-0 (0.0)	0-3 (0.8)	0-0 (0.0)	0-1 (0.3)	0-3 (1.2)	0-0 (0.0)	0-2 (0.4)	0-3 (1.4)	0-0 (0.0)	0-1 (0.1)	0-5 (1.4)
1991-00	0-0 (0.0)	0-0 (0.0)	0-0 (0.0)	0-0 (0.0)	0-2 (0.3)	0-2 (0.6)	0-0 (0.0)	0-0 (0.0)	0-0 (0.0)	0-0 (0.0)	0-1 (0.1)	0-3 (1.0)
2001-10	0-1 (0.1)	0-0 (0.0)	0-2 (0.5)	0-0 (0.0)	0-1 (0.2)	0-1 (0.4)	0-0 (0.0)	0-0 (0.0)	0-0 (0.0)	0-0 (0.0)	0-0 (0.0)	0-3 (1.0)

Tab. 4 - Decadal range and average of number of days of extreme temperature (Tmin < 10°C, Tmax > 35°C) and rainfall (RF > 50mm) at north-west Bangladesh during Boro season, 1971-2010.
Tab. 4 - Variazioni decennali e media del numero di giorni con temperature (Tmin < 10°C, Tmax > 35°C) e precipitazioni (RF > 50mm) estreme nel nord-ovest del Bangladesh nel periodo 1971-2010.

The effect of increasing minimum and mean temperatures and reduction of sunshine hours showed decreasing trends of *Boro* rice yields (Fig. 4). But based on regression model, both predicted and observed yields were increasing (Fig. 5). It might be because of adoption of high yielding varieties, improved cultural practices, improved agro-technologies, and ensure irrigation facilities during *Boro* rice growing season.

To sustain *Boro*-rice productivity, there is a need to identify suitable adaptation strategies, viz. optimum sowing/transplanting window for the region, choice of suitable cultivars/ideo-types, adoption of appropriate water and nutrients management strategies, and adoption of appropriate resource conservation technologies. For this purpose, use of INFOCROP, DSSAT models are needed to be integrated with relational layers of bio-physical and socio-economic aspects. We have started using these simulation tools for evaluating the impact of climate change and its variability on soil and crops' productivity and suggesting suitable mitigation and adaptation strategies for agri-sustenance.

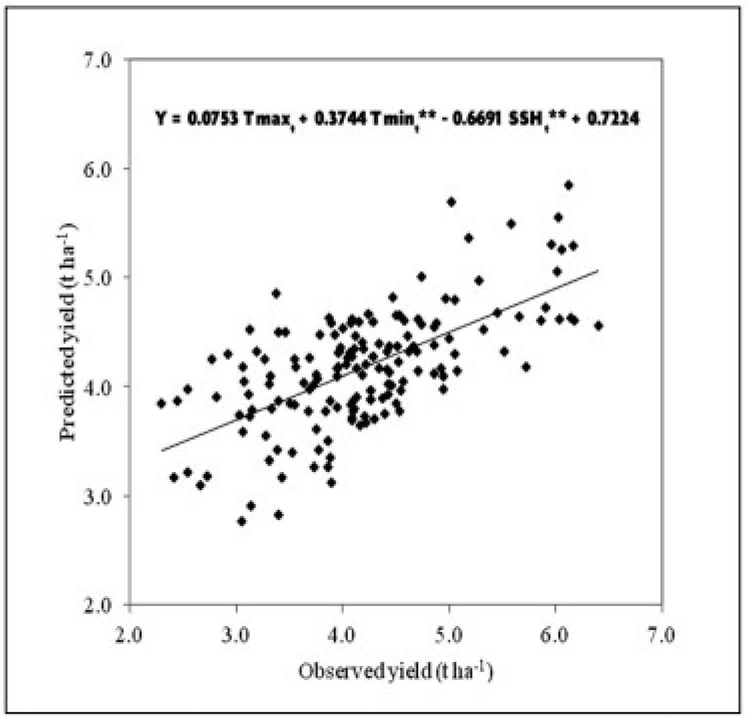

Fig. 5 - Multiple regression of maximum (Tmax) and minimum (Tmin) temperatures and sunshine hours (SSH) on Boro rice yield in north-west region of Bangladesh.
Fig. 5 - Regressione multipla delle temperature massima (Tmax) e minima (Tmin) e delle ore di sole (SSH) sulla resa di riso Boro nel nord-ovest del Bangladesh.

CONCLUSIONS

The trend line analysis was done based on annual and seasonal climatic variables based on MAKESENS model. Historic weather in northwest parts of Bangladesh indicated inter-annual and inter-seasonal climatic variability, as well could indicate the climate change trend in terms of increased temperatures, rainfall and reduction in sunshine hours. Most of the GCMs also show the similar trends, with few exceptions, which might be due to approximations in the regional calibration. In this study, attempt was made to characterize inter-seasonal climatic variability through growth response of

Boro rice. Climatic elements, maximum and minimum temperatures and sunshine hours, were related to *Boro* rice yields through percent deviation from the normals (for weather parameters) and from trend line for *Boro* rice productivity, and performance was satisfactory within level of significance. Multiple regression analysis, by including maximum and minimum temperatures and sunshine hours (seasonal) were used as independent variables could satisfactorily predict *Boro* -rice yields in four test locations in north-west Bangladesh. The extreme temperatures and rainfall may create adverse effect on *Boro* rice yield, which ultimate would reduce rice production as a whole for the country. The study clearly indicates the usefulness of the regression based approach for evaluating the impact of climatic variability on growth and yield of crops, however there is a need to include other biotic and abiotic stresses which are operative simultaneously along with climatic conditions for precise estimates. For this purpose, use of simulation tools and artificial intelligence systems are to be employed. We are already working on these advanced tools for climate change impacts analyses studies.

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